METHOD AND SYSTEM FOR CHECKING THE POSITION OF A MECHANICAL PART WITH A LIGHT
BEAM

5   Technical Field

The present invention relates to a method for checking the
position of a mechanical part along at least one checking
10   direction by means of an apparatus including a device for
generating a light beam along a trajectory transversal to
the checking direction, a sensor for detecting the
interruption of the light beam, and devices for causing
mutual displacements between the mechanical part and the
15   light beam along the checking direction and along an
inspection direction transversal to the checking direction.
This invention also relates to a system for checking the
position of a tool coupled to the turret of a machine tool.

20   Background Art

Apparatuses for automatically checking the position or the
integrity of tools are often utilized in machine tools of
various types as, for example, numeric control machining
25   centers where the condition of the tools can be checked in
the course of the actual machining phase when the tool is
coupled to the rotating spindle.
Known apparatuses and methods perform checkings of this
type, i.e. determine the presence, the position, the
30   dimensions and possible breakages of tools, by utilizing
feelers for contacting the tools, or contactless systems
as, for example, optical systems that employ light rays or
beams.
U.S patent No. US-A-3912925 discloses a drilling machine in
35   which devices for checking the integrity of the tools
utilize transversal light beams with limited thickness. The
beams are substantially coplanar to the feed direction of

the tools. The non-interruption of a light beam at a specific position of the tool is detected and notifies an anomalous condition of the tool.

Different applications of optical or optoelectronic systems
5   for checking the position and/or the dimensions of non-rotating tools with profile not a priori precisely known present specific problems. This is the case, for example, when checking tools located in the tool-holder ("turret") of a lathe and it is required to accurately check the
10   position of the cutting edge of these tools.

A specific problem rises whenever expensive and delicate devices with thick linear sensors that employ an equally thick light beam enabling to detect and to analyze the entire profile of the tool (for example "shadow-casting"
15   systems) cannot be used and it is desired to utilize apparatuses in which there is simply detected the interruption of a light beam (for example a laser beam) with limited thickness. The posed problem is to find the correct arrangement between tool and light beam that
20   enables the former to interfere with the latter at the significative dimension to be checked, since the position of the significative dimension along the entire profile of the tool is not a priori known.

A solution proposed, for example, in patent No. US-A-
25   3749500 (figure 17, column 16, lines 4-21) is to arrange the optoelectronic apparatus in such a way that the beam lies in the plane that includes the profile of the tool to be checked, substantially perpendicular to the direction of the dimension to be checked. In many cases this possible
30   solution is not applicable by reasons of insufficient room available. Moreover such solution is not really flexible because it does not enable to carry out checkings of different tools – for example, tools mounted in different positions on the same turret – the significative profile of
35   which, i.e. the profile that includes the cutting edge to be checked, lies in different planes. Therefore, it is necessary to add complexity to the system by foreseeing the

possibility of displacing the beam perpendicularly to the planes of the profiles or vice versa and to identify the correct position by performing an additional scan in said direction.

5   Furthermore, the checkings that the solution disclosed in patent No. US-A-3749500 enables to perform are limited to a single direction along the significative profile plane, i.e. perpendicular to the light beam. This means the preclusion, unless arranging a plurality of light beams in

10   other ways, to checkings of tools with cutting edges that include - as often occurs - conceptually punctiform working areas with different orientations along the significative profile plane.

Therefore, it is preferred to resort to a different

15   arrangement of the optoelectronic apparatus, in which the light beam lies in a transversal direction (more particularly, a perpendicular direction) to the plane of the tool profile.

Figure 1 schematically shows a cross-section view along

20   plane X-Z of a mechanical part U that includes an end point C, along direction X, the position thereof is to be checked along the same direction X (checking direction). Figure 1 also shows the cross-section view along the same plane X-Z of a light beam R arranged along a direction Y

25   perpendicular to the plane X-Z. The mechanical part U schematically represents, for example, a tool mounted in the turret of a lathe and including, in a position along the plane X-Z not a priori known, a cutting edge C the position of which along the direction X is to be located.

30   A method of performing the checking foresees identifying the trend of the profile B - not a priori known - of the part U along the cross-section plane, by a point scan of the profile. If the tool to be checked is located in the turret of a lathe, the scan is performed, for example, by

35   displacing the turret along directions X and Z according to sequences of a known type, by detecting interruptions of the light beam R at a plurality of points of the profile B,

and by performing processings, also of a known type, including, for example, interpolations for locating points of the profile **B** not "contacted" by the beam **R**.

This known method may pose reliability problems bound to the selected scan interval, type of scan (greater or lesser number of points to be checked and consequent longer or shorter involved time) and consequent necessary processings. In fact, an inaccurate or incomplete detection of the profile may cause – in the formerly mentioned example – the missed identification of the point **C** of maximum projection in the direction **X**, the position of which has to be checked.

In any case, the known method is time consuming and involves complex processings.

Disclosure of the Invention

An object of the present invention is to provide a method and a system for checking the position of a tool, more specifically the cutting edge of a tool the profile of which is not known a priori, that is simple and reliable, overcoming the disadvantages that the known methods and systems present.

This and other objects and advantages are achieved by a method according to claim 1 or claim 11 and by a system according to claim 13.

Among the advantages that the method according to the present invention and the associated system provide, there are the remarkable rapidity of the feasible checkings and the possibility of identifying – by means of the same apparatus and in an extremely simple and rapid way – the position of working areas of the tool, i.e. the points of the cutting edge oriented for performing machinings along different directions.

Brief Description of the Drawings

The invention will now be described with reference to the enclosed sheets of drawings, given by way of non limiting example only, wherein:

5   figure 1 is a schematic and partial representation of a mechanical part to be checked by means of a method according to the invention;

        figure 2 shows in simplified form an application on a machine tool that implements a system according to the invention;

10   figure 3 is an enlarged and partial view of a tool of the machine tool of figure 2, along direction Y in figure 2;

        figure 4 is a diagram with blocks that represent the various steps of a method according to the invention; and

15   figure 5 is a furtherly enlarged and partial view of the tool shown in figure 3, including a graphical representation of a sequence of displacements in a checking method according to the invention.

20   <u>Best Mode for Carrying Out the Invention</u>

Figure 2 illustrates, in an extremely schematic form, a checking system including an optoelectronic apparatus **1** in the course of checking a mechanical part **2**, more
25 specifically a tool located in a turret **3** of a lathe **4** to which the apparatus **1** is coupled. Typically, the turret **3** carries other tools, not shown in the schematic representation of figure 1. The apparatus **1** includes an emitter **6**, i.e. a device for generating a light beam **7**, for
30 example a laser beam, along a transversal trajectory substantially parallel to direction **Y**, and a receiver **8**, i.e. a sensor, arranged along said trajectory, that detects the correct reception of the light beam **7** or the non-reception of light owing to the interruption of the beam **7**.
35 A processing unit **9** is electrically connected to the emitter **6** and to the receiver **8**. The system includes a control unit **10**, connected to the processing unit **9**, for

controlling in a known way, by means of suitable activation devices also known and not illustrated in the figure, the machining movements of the lathe **4** in plane **X-Z** of the turret **3** that carries the tool **2**. For the sake of

5   simplicity and for the reason it is beyond the object of the present invention, a spindle of a known type holding a piece to be checked arranged, for example, in the direction **Y**, is not illustrated.

The surface contour or profile of the tool **2** in the plane

10   **X-Z** is shown enlarged in figure 3, where a checking area **13** of the position of the tool **2** is delimited by a first linear interval **X1** and by a second linear interval **Z1**. The first linear interval **X1** and the second linear interval **Z1** along the checking direction **X** and an inspection direction

15   **Z**, respectively, are defined on the basis of the approximately known nominal dimensions of the tool **2** and delimit the mutual positions that tool **2** and light beam **7** can take in the course of the checking, as hereinafter described. The correct arrangement and dimensions of the

20   area **13** are defined in an initial phase of the checking cycle, as hereinafter also described.

The blocks of the diagram of figure 4 refer to a procedure for checking the position of a working area **11** of the tool **2** along the direction **X**. In an entirely analogous and

25   symmetrical way – not hereinafter described – the checking of the position of a working area **12** of the tool **2** along the direction **Z** is implemented. The various steps of the procedure and the mutual movements between the tool **2** and the light beam **7** can be checked, for example, by the

30   control unit **10**.

The meaning of the blocks represented in figure 4 is hereinafter briefly described.

        block **18** – start of the checking cycle;

        block **19** – acquisition, for example by means of the

35   control unit **10** of the lathe **4**, of the data relating to a tolerance value **W** and to the approximate nominal dimensions of the tool **2**, and consequent setting of the checking area

13;

block **20** – displacements between tool **2** and beam **7** for bringing the latter to a first predetermined vertex **14** of the perimeter of the checking area **13**;

block **21** – test about interruption or non-interruption of the beam **7** at the vertex **14**;

block **22** – modifications of the checking area **13** and of the mutual arrangement tool **2** / beam **7**;

block **23** – displacements between tool **2** and beam **7** along the perimeter of the checking area **13** starting from a vertex **(14,15,16)**;

block **24** – test in connection with the reaching of the subsequent vertex **(15,16,17)**;

block **25** – test about the interruption of the beam **7**;

blocks **26** and **27** – tests for determining whether the in-progress displacement is the last foreseen (between the vertexes **16** and **17**);

block **28** – initial setting of procedure parameters, i.e. indicator **T0** of the result of the immediately previous checking, indicator **V** of the sense of the next displacement along the checking direction **X**, amount **D** of the next displacement, in addition to the value of a reduction factor **FR** of the subsequent displacements along the checking direction **X**;

block **29** – displacement between tool **2** and light beam **7** for bringing the beam **7** to a determined inspection position **Pi**; this displacement includes a component along the checking direction **X** of amount **D** in the sense **V**;

block **30** – linear inspection movement between tool **2** and beam **7** along the second direction **Z** in the linear interval **Z1**;

block **31** – test for determining the completion of the inspection movement in the entire linear interval **Z1**;

block **32** – test for determining the interruption of the beam **7** in the course of the inspection movement;

block **33** – indication of the non-interruption of the beam **7** in the course of the inspection movement (**T=0**);

block **34** – indication of the interruption of the beam **7** in the course of the inspection movement (**T**=1);

block **35** – comparison between the values of the indicators **T** and **TO**;

5   block **36** – confirmation of the sense **V** of the next displacement along the checking direction **X**;

block **37** – test for determining the end of a search phase on the basis of a comparison between the tolerance value **W** and the distance **D** between recent mutual positions

10   between beam **7** and tool **2** in the direction **X**;

block **38** – reversal of the sense **V** of the next displacement along the checking direction **X**;

block **39** – updating of some parameters (**TO←T**; **D←D/FR**);

block **40** – comparison between the inspection position **PN**

15   of the beam **7** in the checking direction **X** at the end of the search phase and a corresponding position defined in a calibration phase;

block **41** – end of the checking cycle.

The checking of the position of the working area **11** of the

20   tool **2** along the direction **X** by following the procedure of figure 4, that represents a possible embodiment of a method according to the present invention, occurs in the following way.

At first (block **19**), depending on the values of the

25   approximate nominal dimensions of the tool **2** and on the known arrangement of the tool **2** in the turret **3** with respect to the reference system of the machine tool, the first linear interval **X1** and the second linear interval **Z1**, that locate the checking area **13** within which the checking

30   displacements between tool **2** and beam **7** are limited, are defined.

Then a preliminary verification phase follows for verifying whether the set linear intervals (**X1** and **Z1**) enable the correct performing of the checking. In order to do this,

35   the tool **2** and the beam **7** are displaced with respect to each other (block **20**) in order to bring the latter to a vertex **14** of the rectangle that delimits the area **13**. If

the interruption of the beam **7** (block **21**) at the vertex **14**
is observed, it means that the checking area **13** has not
been correctly selected. As a consequence, the preliminary
phase is interrupted, displacements of the tool. **2** are
controlled for bringing the beam **7** to a position definitely
at the exterior of the area **13**, and fresh linear intervals
X1 and **Z1** (block **22**) are set. If the interruption of the
beam **7** is not observed, mutual linear displacements (block
23) are controlled in sequence for bringing the beam **7** from
a vertex **(14,15,16)** towards the subsequent one **(15,16,17)**
along the sides of the rectangle that delimits the area **13**.
At every displacement it is verified whether the subsequent
vertex has been reached (block **24**). The preliminary phase
is interrupted and the limits of the checking area **13** are
reset (block **22**) whenever there occur anomalies. The
anomalies are signalled by interruptions of the beam **7** in
the course of the displacements towards the vertexes **15** and
16 (blocks **25** and **27**) or, in the last foreseen displacement
– i.e. an inspection movement in the direction **Z** starting
from the vertex **16** – by the non-interruption of the beam **7**
and the reaching of the vertex **17** (blocks **24** and **26**). The
verification preliminary phase otherwise positively ends
when the beam **7** is correctly interrupted in the course of
the inspection movement that starts from the vertex **16**
(block **27**).
Then the initial or absolute values of some parameters
utilized in the subsequent actual checking phase are set
(block **28**). The parameters are hereinafter briefly
described.
   TO: it indicates the result of the immediately
previous inspection with respect to the in-progress one,
i.e. it indicates whether, in the course of the previous
inspection movement between tool **2** and beam **7** (the
following explanation refers) the interruption of the
latter occurred (**TO=1**) or did not occur (**TO=0**). At first,
TO is set, for example, at value 1, also on the basis of
the conclusion of the verification phase.

V: it indicates the sense of the next mutual displacement between tool **2** and beam **7** (the following explanation refers) insofar as the component in the checking direction **X** is concerned. With reference to figure

5   3, **V**=1 and **V**=0 indicate, for example, displacements to the right and to the left, respectively. At first **V** is set, for example, at value 1.

D: it is the amount of the displacement along the direction **X** to which **V** refers. At first **D** is set, for

10 example, at a value that corresponds to the length of interval **X1** reduced by the reduction factor **FR** (hereinafter described).

FR: it is the reduction factor relating to each displacement in direction **X** that follows in the checking

15 sequence. In general, it is a fixed value. In the herein described example **FR**=2, i.e. the amount of the displacement along **X** is halved every time with respect to the previous displacement along the same direction **X**.

The search phase of the position of the working area **11** of

20 the tool **2** foresees a sequence of checking displacements between tool **2** and beam **7** starting from the position taken at the end of the preliminary phase in which the beam **7** is at a point on the side defined by vertexes **16** and **17** that delimits the first linear interval **X1**. It should be

25 realized that, in the present description, the search phase is distinguished from the preliminary phase described above with reference to the blocks **20-27** for more clearly describing a method according to the invention. The search phase actually follows the preliminary phase with

30 substantial continuity.

A displacement (block **29**) between the tool **2** and the beam **7** towards a determined mutual position is controlled so that the beam **7** displaces to a determined inspection position **Pi** on the lower side (with reference to the arrangement shown

35 in figure 3) of the checking area **13**, at a distance along axis **X** determined on the basis of the parameters **V** and **D**. More specifically, the sense **V** and the amount **D** of the

first displacement in direction **X** with respect to the vertex **16** are those previously set (**V=1; D=X1/FR=X1/2**).

At inspection position **Pi** in the interval **X1**, a linear inspection movement is controlled (block **30**) along direction **Z** and it interrupts when one of the two following events occurs (i) the reaching of the opposite side of the checking area **13** when the beam **7** has travelled, in the linear movement, the entire interval **Z1** (block **31**); or (ii) the interruption of the beam **7** signalled by the optoelectronic apparatus **1** (block **32**). The event regarding the occurred interruption (**T=1**, block **34**) or non-interruption (**T=0**, block **33**) of the beam **7** is compared (block **35**) with the corresponding event that occurred in the immediately previous inspection, indicated by the parameter **TO** and, depending on whether the event has or has not repeatedly occurred, the sense in which the subsequent displacement along direction **X** will occur is held (**V←V**, block **36**) or reversed (**V←invV**, block **38**), respectively.

The values of some parameters are updated (**TO←T, D←D/FR=T1/4**, block **39**) and the checking sequence is repeated starting from a fresh displacement (block **29**) between tool **2** and beam **7** towards a fresh determined mutual position, in such a way that the beam **7** displaces to a fresh inspection position **Pi** at the lower side of the checking area **13**, at a distance from the previous inspection position set on the basis of the values of parameters **V** and **D**. A fresh linear inspection movement (block **30**) along direction **Z** is controlled at the fresh inspection position **Pi** in the interval **X1**.

The sequence of checking displacements ends when, after having verified that **T ≠ TO** (block **35**), the distance **D** between the current position and a previous one of the beam **7** in the interval **X1**, more specifically the immediately previous position, is less than the prefixed tolerance value **W** (block **37**).

The final inspection position **PN** taken by the light beam **7** in the linear interval **X1** at the end of the sequence of

checking displacements is compared with the corresponding
position detected in a previous calibration phase on a
master piece for determining the position of the working
area **11** of the tool **2** to be checked (block **41**). Calibration

5   is performed in a known way for correlating the absolute
position of the machine axes of the lathe **4** with the one of
the area **11** to be checked in a suitable reference system.
If the position of the master piece with respect to the
machine axes is known, a possible calibration procedure,

10 herein not detailedly described for the sake of simplicity,
can be performed on the master piece in a substantially
identical way with respect to the one described with
reference to the blocks **19-39** of the diagram shown in
figure 4.

15 Then, from the position of the working area **11** and by
knowing, as formerly mentioned, the arrangement of the tool
2 in the turret **3** with respect to the reference system of
the machine tool, the dimensions of the tool **2** in the
checking direction **X** can be determined.

20 In figure 5 the checking area **13** is furtherly enlarged and
there are shown the linear inspection movements along
direction **Z** (as uninterrupted lines) and the displacements
with component in direction **X** (as dashed lines). In the
example illustrated in figure 5, it is presumed that the

25 tolerance value **W** is equal to a tenth of the amplitude of
the interval **X1** (**X1**/10). This value has been chosen just
for the sake of simplifying the explanation of the cycle,
and is definitely greater than an actual tolerance value.
Furthermore, also for the sake of simplifying the

30 explanation, movements of the light beam **7** in the checking
area **13** are reported, while in the real applications the
beam **7** is generally stationary with respect to the bed of
the machine tool **4** (figure 2) and the turret **3** carrying the
tool **2** (to which the area **13** is associated) performs

35 movements in the plane **X-Z**. This corresponds to the
substance of the method that includes, according to the
invention, mutual movements between tool **2** and beam **7**.

With reference to figure 5 and to the orientation therein
shown, at the end of the preliminary phase for the
verification of the checking area **13** (blocks **25** and **27**),
the beam **7** interferes with the tool **2** at the side between
the vertexes **16** and **17** that delimits the linear interval
X1. The beam **7** is brought back to the lower side of the
checking area **13** displaced to the right with respect to the
vertex **16** (**V**=1, block **28**) of the amount **D**=**X1**/2 up to
inspection position **P1** (block **29**) where an upward
inspection movement in the direction **Z** is controlled (block
30). Since the interruption of the beam **7** is detected
again, a fresh downward and, in the interval **X1**, rightward
displacement of an amount halved with respect to the
previous one (**D**=**X1**/4) takes place, up to inspection
position **P2**. The subsequent inspection movement at **P2**
causes a different event, i.e. the reaching of a point **P2'**
at the opposite end of the interval **Z1**, on the upper side
of the checking area **13** (blocks **31**, **33**). As **T**(=0) ≠ **T0**(=1)
(block **35**), the sense of the displacement along **X** is
reversed (**V**← inv**V** = 0, block **38**) and the beam **7** is brought
back to the lower side of the checking area **13** displaced to
the left with respect to **P2** of the amount **D** = (**X1**/4)/2 =
X1/8 up to inspection position **P3**. At the subsequent
inspection movement at **P3**, the event changes again
(interruption of the beam **7**) and thus the sense **V** of the
subsequent displacement changes again (**V**← inv**V** = 1, block
38) on the lower side of the area **13** and to the right, up
to inspection position **P4** that is distant from **P3** in the
checking direction **X** of the amount **D** = (**X1**/8)/2 = **X1**/16. A
fresh inspection movement ends when the beam **7** reaches the
upper side of the checking area **13**, at a point **P4'** (blocks
31, **33**). As **T** ≠ **T0** (block **35**) and **D** < **W** (**X1**/16 < **X1**/10,
block **37**), the sequence of checking displacements ends, and
the position of the working area **11** is determined (block
41) on the basis of the final inspection position **PN** = **P4**
in the linear interval **X1**.

The illustrated example clearly shows how the position of

the working area **11** is found by means of a limited number of scans in the transversal inspection direction **Z** at inspection positions along the checking direction **X** at distances **D** progressively decreasing with respect to each other in a sequence that converges to the searched position. As already mentioned in the example illustrated with reference to figure 5, the tolerance value **W** has been chosen of a different order of magnitude with respect to what is normally requested and the displacements along the checking direction **X**, required for completing the checking cycle, are limited to four. In any case the example clearly demonstrates how rapidly the sequence of inspection positions **Pi** along the checking direction **X** converges to the searched position **PN**. In a real example, where the interval **X1** is of a few millimeters and the tolerance value **W** is of a few microns, the necessary inspection movements are generally equal to or slightly greater than ten.

The described procedure represents just an example of a checking method according to the invention that foresees many possible variants. For example, the sequence of checking displacements can start from a mutual position that differs from the one described (that is determined in the preliminary verification phase), in case that, for example, the verification phase is unnecessary or is performed at a different moment in time. Moreover, the sequence of checking displacements can be stopped on the basis of the result of a different test, for example the comparison of the set tolerance **W** not with the distance **D** between the last two consecutive inspection positions **Pi** at which there have occurred opposite events, but with the distance between the current inspection position **Pi** and the last inspection position **Pi** at which there occurred the event opposite to the current one, regardless of the comparison between the events relating to the last two consecutive inspection positions **Pi**.

Other variants can regard the implementation of the displacements. Just as an example, three possible aspects

that differ with respect to what has been herein so far described and illustrated are cited.

- A reduction factor **FR** different from 2 can be chosen, for example it can be 3, or can assume a value that varies in the course of the checking cycle, for keeping into account the sequence of the events that have taken place. However, the reduction factor **FR** is chosen in such a way that the succession of the inspection positions **Pi** on the checking direction **X** converges to the position of the working area the position thereof has to be checked.

- The inspection positions **Pi** in the interval **X1** can be in the upper side (according to the arrangement shown in the figures) of the checking area **13**, or alternatively in the lower side and in the upper one. This latter solution can be advantageously applied, for example, further to the occurring of the event according to which the interruption of the beam **7** is not detected. In this case, in the example of figure 5, the beam **7** is displaced from point **P2'** to a closer point **P3'** on the upper side of the area **13** that corresponds, in the interval **X1**, to the inspection position **P3**, whereas the subsequent linear inspection movement in the direction **Z** (block **30**) occurs, as a consequence, downwards.

- The displacements that follow the inspection movements occur, in the example shown in figure 5, with interpolated movements that include components along both directions **X** and **Z** ("saw-toothed movements"). Obviously this is not the only possible solution and the displacements can occur in two distinct phases (for example: return to the side of the checking area by a movement along **Z**, followed by a linear movement along **X** to the inspection position **Pi**).

As previously described, the description and the figures refer to the checking of the position along the axis **X**. By following an identical procedure, it is possible to check positions of working areas along the direction **Z** (area **12**

in figure 3) or along other transversal directions of the
plane **X-Z**.

This is particularly advantageous as it enables to carry
out a complete verification of the cutting edges of the
5   tools for checking associated points, or working areas,
oriented in different directions. In the example shown in
simplified form in figure 3, both the working areas **11** and
12 can be, for example, simply and rapidly checked in
sequence.

10 A method according to the invention enables the checking of
different types of tools in different applications, and in
general mechanical parts of various type (for example,
workpieces before or after the machining).